

## SEGIS Smart Grid Inverter with Utility Communications and Optional Energy Storage



Benefits: More Reliable, Lower Cost Solar Power

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## SEGIS Smart Grid Inverter Systems Integration

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## Timeline

- Project start date: 7/22/2009
- Project end date: 6/18/2010
- Percent complete: 95%

## Budget

- Total project funding: \$1,912,422
    - DOE share: \$1,529,938
    - Contractor share: \$ 382,484
  - Funding received in FY09: 0%
  - Funding for FY10: 100%
- (Meaning the funding received by Apollo Solar and a June 30 year end)

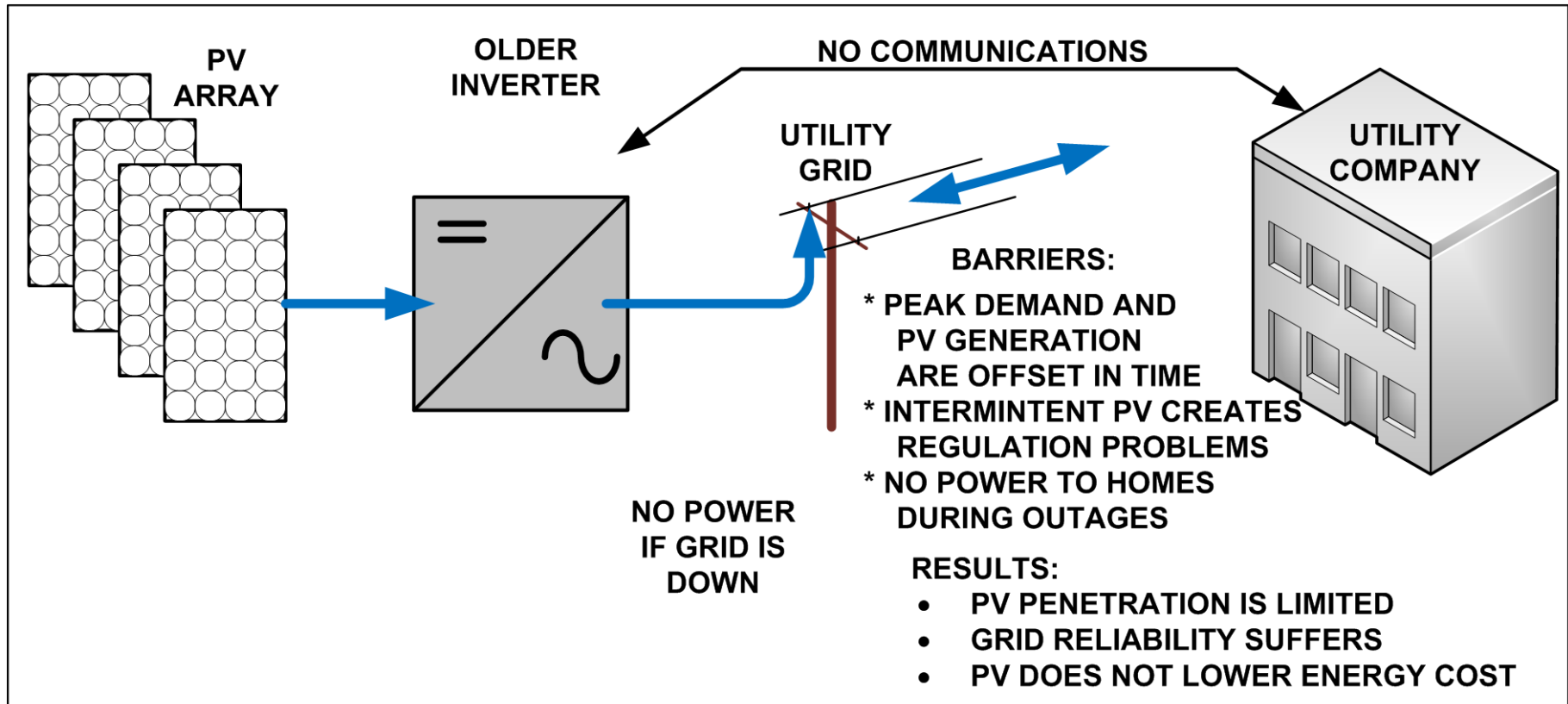
## Barriers

- Market Challenge: Confirming to the Utilities the value of the Dispatchable Power and Grid Protection provided by adding energy storage to PV Inverters
- The Manufacturing Cost of More Efficient, More Reliable, Safer, and More Controllable PV Systems that Increase Value to System Owners
- Market Acceptance of the Innovative Transformerless Inverter topology that reduces system cost, increases efficiency and reliability, and enhances safety

## Partners

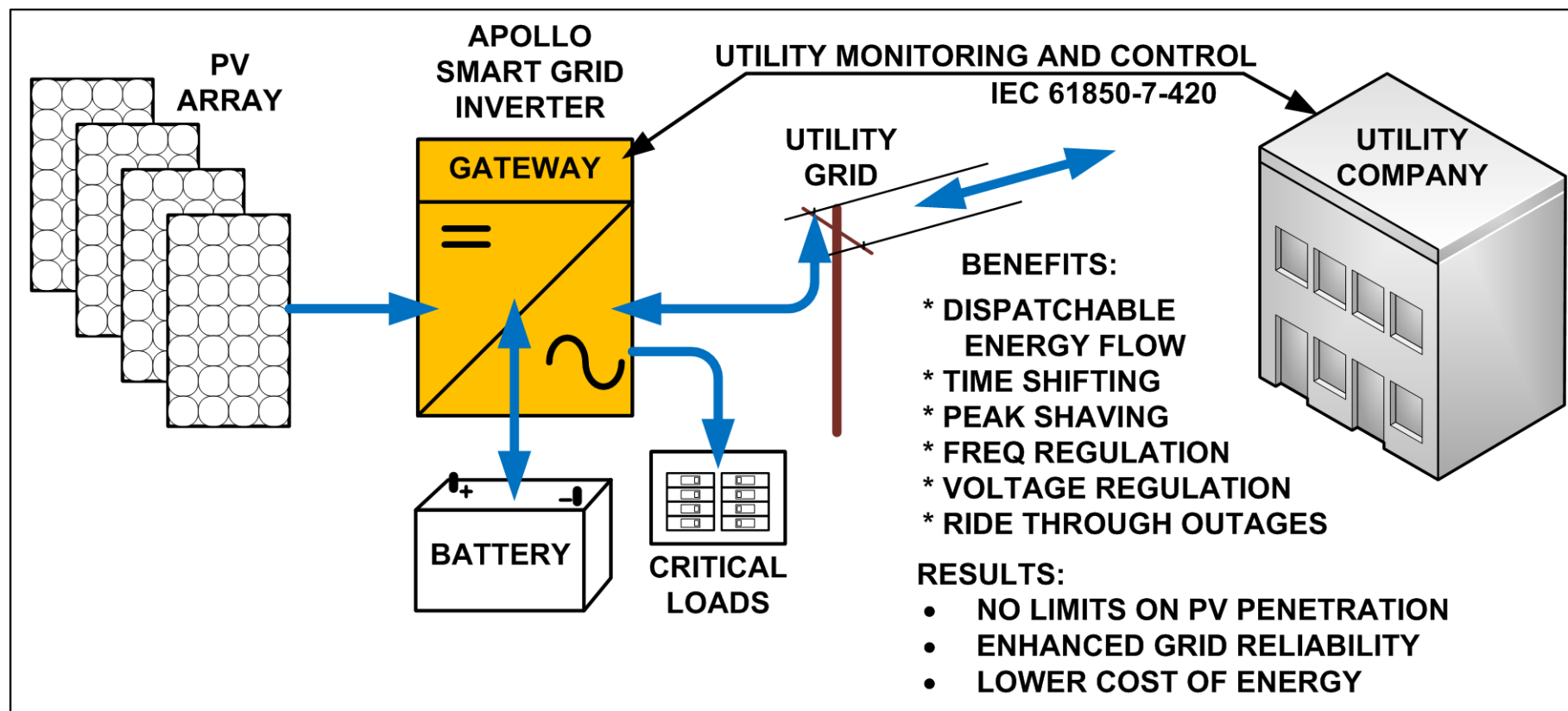
- Apollo Solar, Inc. – Project Lead
- EPRI
- VPT Energy Systems
- Oak Ridge National Laboratory
- United Illuminating Company
- Saft Batteries
- Ablrex Electronics Co.
- Brooks Engineering
- Solar ABCs

## Residential Solar Electric Installation BEFORE our SEGIS Smart Grid Inverter



Apollo Solar effectively addressed all the barriers and created a Smart Grid Inverter which can lower the cost of grid tie photovoltaics in the near term.

## Residential Solar Electric Installation WITH our SEGIS Smart Grid Inverter



Changing to the Apollo Solar Smart Grid Inverter with Utility Communications and Energy Storage overcomes the barriers, lowering the LCOE of PV.

## The Apollo Smart Grid Inverter system



The Apollo Solar SEGIS Smart Grid Inverter system consists of a transformerless, dual mode (current and voltage source) Grid Tie Inverter, an Energy Storage Converter to interface with batteries, and the Apollo System Controller with communication to utilities

Apollo  
System  
Controller



Apollo Transformerless Grid Tie Inverter



## **The market challenges and other barriers are:**

1. Providing the data communication protocol/module that delivers the grid power protection and coordination required by the electric utility industry
2. Market acceptance of the innovative Transformerless inverter topology that reduces system cost, increases efficiency and reliability, and enhances safety
3. Providing a highly reliable advanced inverter/controller that functions in both grid-tied and stand-alone modes and meets the requirements of UL1741, IEEE1547 and NEC690

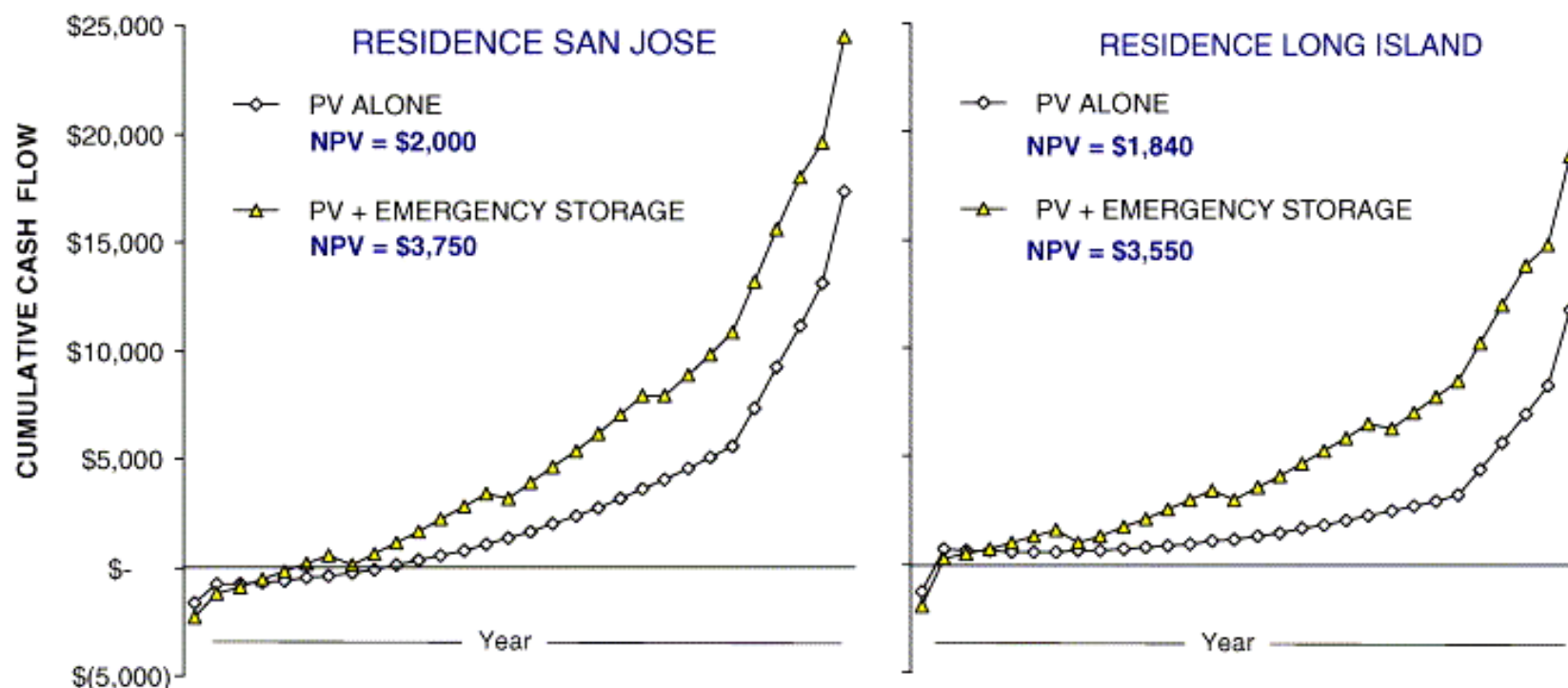
## **The challenges and barriers are addressed in that order by.....**

1. Working with EPRI to implement the IEC 61850-7-420 Communications that provide monitoring, command, and control of the power flows requested by the utility industry
2. Developing a high quality, market-viable Grid Tie Transformerless Inverter with the benefits of increased efficiency, higher reliability, and the value-added benefits of energy storage to the utilities and their customers
3. Implementing a unique topology that results in minimal energy loss for power flows in all directions while remaining inherently low-in-cost to manufacture

## **The Apollo Solar objectives are relevant and critical to the EERE Solar Program and fully support the DOE RD&D objectives.**

1. The **objective** of the Apollo Solar SEGIS project matches the goals of the DOE and SEGIS of creating an advanced inverter whose lower part-count provides higher reliability and efficiency at a lower cost, reducing the LCOE. The addition of Energy Storage and Data Communication for the utilities allows them to control the bi-directional energy flow, maximizing the economic benefits of grid-integrated PV.
2. The addition of energy storage allows the distributed generation systems to continue to supply power to meet customer needs during grid disturbances. The relevance and economic value is shown in the graphs on the next 2 slides which compare the value of systems of PV with and without storage.
3. During the period March 2009 to May 2010, Apollo brought the project from the market analysis/feasibility study stage through design and development to a working prototype.
4. By making the energy storage an optional part of the grid tie inverter, according to the results of our detailed market study, the combined product meets the expectations of the home/business owner, the system installer, and the local electric utilities.
5. Integral to the Inverter System is the Apollo System Controller that provides utility communication protection and coordination to address the technical concerns relating to large quantities of distributed PV generation, increasing the value of the PV to the utility.
6. The comprehensive approach of the Apollo SEGIS Advanced Inverter/Controller is to combine the ability of the PV to power the local load with the ability of optional energy storage to provide the benefits of Grid Peak-Shaving, Demand Response, and Load Shifting based on Time-of-Use Rates. These economic benefits to the utility then become economic benefits that further offset the life-of-system cost of PV, reducing further the LCOE of the solar electricity.

Energy Storage, when added to PV systems lowers the overall cost of the energy. As shown in the graphs below, the net present value of these residential PV systems were substantially increased by adding batteries, referred to here as emergency storage.



Cumulative cash flow for residential customers – comparing PV-alone and PV + emergency storage options.

Data from: *Maximizing the value of customer-sited PV systems using storage and controls* by Thomas E. Hoff, Richard Perez, and Robert M. Margolis , 2007

## Our Technical Approach

- **Lower the cost of the Inverter.** Since one barrier to lowering the cost of solar power, in addition to the cost of the PV array, is the cost of the Balance of System components, Apollo focused first on finding a new approach to building an inherently lower-cost grid-tie inverter. We analyzed the manufacturing costs of the existing products and interviewed many installers and distributors to find ways to reduce installation costs. We then developed a unique inverter topology that eliminates the transformer, which cuts manufacturing cost, increases efficiency, enhances reliability, and makes the installation faster and less expensive.
- **Add Data Communications with the Utility.** By providing data communications with the utility and the option of adding a battery for storage, the unique Apollo topology addresses many of the technical barriers to increasing the amount of solar which can be added to the grid. We approach the major non-technical market barrier of a lack of standardization by placing a corporate officer of Apollo Solar on the task force at EPRI working on the standards for the Interactions and Communications protocols that will enable the protection and coordination with the electric utility industry across the entire country.
- **Timeline.** Apollo is adhering to the timeline defined by the SEGIS Program. The feasibility and market study/analysis was completed in May 2009 and the Stage 2 prototype was demonstrated in May 2010. Apollo is ready to complete the commercialization of the Advanced Inverter/Controller in Stage 3 of the SEGIS contract.

- **Focus on Barriers - Risk Minimization.** We evaluated the technical barriers in terms of the degree of risk each brought to delaying the completion of the project. The 2 most significant barriers were the lower-cost design of the more efficient and reliable grid-tie inverter and the length of time involved in the UL certification testing. A 3<sup>rd</sup> risk/barrier was that the compliance of the final design to UL standards could result in lessening the reduction in final manufacturing costs. Our approach was to carefully and specifically address all of those risk/barriers from the beginning so they could be avoided/minimized .
- **Created a Unique Topology to Avoid the Barriers.** We created a new topology within which we use the framework of an existing grid-tie inverter that is already UL certified and in production and with established costs. With units already in the field, the basic reliability data is already available. Further, the Apollo modifications to the hardware itself will not require additional UL certification testing . The firmware has been modified to provide voltage source output for the stand-alone mode, in addition to the current source output used when in grid-tie mode.
- **The Energy Storage** is added using a DC to DC converter connected to the 400 volt DC bus inside the grid-tie inverter. Since Apollo Solar has already commercialized 5kW DC to DC converters, we have been able to address all of the technical barriers related to the energy storage capability of the Apollo Smart Grid Inverter/Controller.

- **VPT Energy Systems** – Contracted to help with technical design and testing of the Energy Storage Converter portion of the system.
- **Saft Batteries** – The supplier of the Lithium Ion battery which is planned for specific customers. Saft and Apollo share technical details on the battery charging and discharging algorithms, parameters and software details. There is no contract in place.
- **EPRI** – The Apollo Solar Chief Operating Officer is a member of the EPRI task force defining inverter Smart Grid interaction and communication with utilities. This task force is using IEC 61850-7-420 protocol. Meetings and interaction is directed by EPRI.
- **Utilities** – Apollo is in discussions with a number of utilities including SMUD, ORNL, and UI regarding demonstration projects incorporating the Apollo SEGIS Smart Grid Inverter system.
- **Ablerex Electronics Company** – Manufacturer of the grid tie inverter for the SEGIS Smart Grid Inverter. Apollo developed the required specifications and hardware/firmware modifications that are implemented with Apollo Solar oversight of the Ablerex engineering group. Ablerex is a full participant and a contract is in place to assure that Apollo Solar has the exclusive rights to sell the Grid Tie Inverter in the US.
- **Brooks Engineering** – Bill Brooks is a recognized industry expert in utility-industry and PV installer training focusing on the requirements of UL1741, IEEE1547, and NEC690. Bill Brooks is a contracted consultant to Apollo Solar.
- **Solar ABCs** – Apollo has a representative engineer participating in all activities of the group that is standardizing PV Installation guidelines. The group is part of the DOE Solar Program.

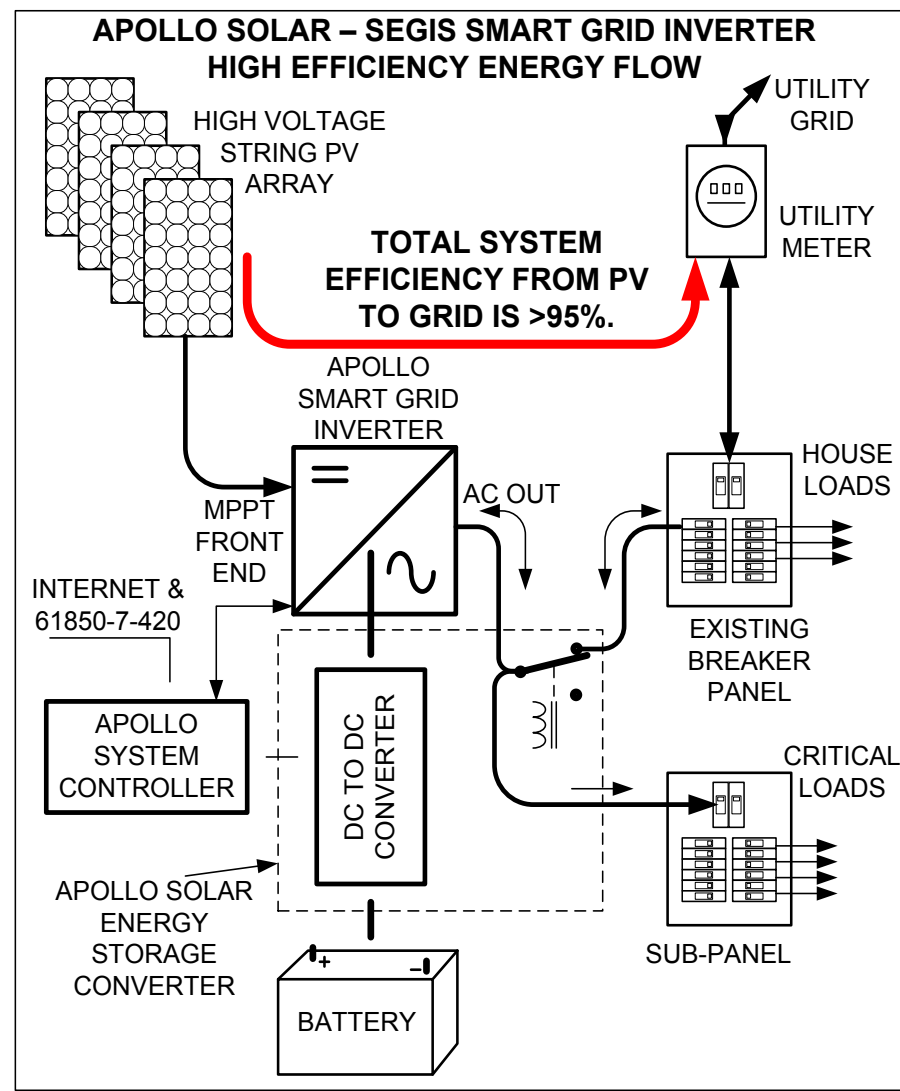
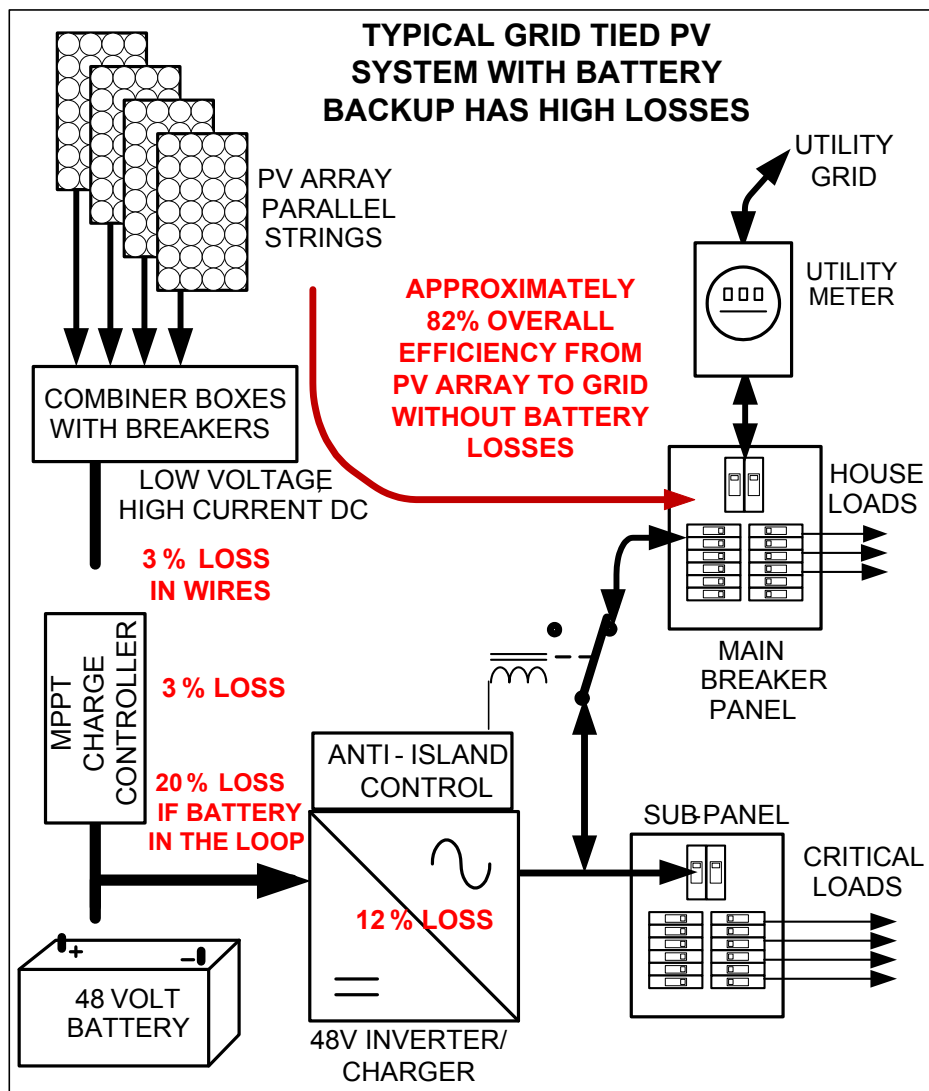
## **Key Technical Accomplishment – Created an advanced inverter system topology to meet the following specific project objectives:**

1. Reduced the cost of the Advanced Inverter/Controller to allow it to compete with existing inverters. By eliminating the transformer and the associated power stages, component and manufacturing costs reduced, product reliability increased, and conversion efficiency enhanced.
2. Developed capability to add energy storage and data communication to an already installed Grid Tie Inverter.
3. Developed capability for transformerless Grid Tie Inverters to charge batteries from PV or the grid.
4. Developed the Energy Storage Converter to enable energy from the battery to be used for critical loads or by the grid via a Transformerless Inverter.
5. Optimized the efficiency of all energy flows by using a maximum of 2 power stages in any path. Maximized the energy flow efficiency from PV to the grid to 95% or better. (Existing grid tie inverters with energy storage topologies suffer from efficiencies from PV to the grid on the order of <85%.)
6. Reduced the system cost by using a single inverter operating as a current source in Grid Tie mode that converts to a voltage source in stand-alone mode to power essential loads as well as to charge the batteries from the grid.
7. Developed capability to allow power flows from all battery cell chemistries and voltages.

**Metrics: Cost of the Grid Tie Inverter reduced from \$0.85/watt to \$0.75/watt MSRP, efficiency from PV to the grid with energy storage increased from <85% to >95%. See diagrams on next page.**

**Using our unique topology, we have reduced cost, added energy storage, increased reliability of the inverter, made energy storage available to the utility, and improved all power flow efficiencies.**

**Our topology accomplishment improves efficiency in flow from 82% to 95% (PV to grid)**



## Technical Accomplishment - Smart Grid Communications

- Apollo Solar has been participating in EPRI's task force to define inverter-utility communications using IEC 61850. The goal is to enable higher PV penetration levels and enhance the value of grid-tie PV and storage devices.
- The Apollo System Controller is designed to support these communications, which include the following functions:
  - Utility can request inverter to turn off or on
  - Utility can request inverter to change maximum generation up or down
  - Utility can request adjustment in power factor
  - Utility can request to charge or discharge storage
  - Utility can send pricing information – current rate and/or scheduled times and rates, so Apollo System Controller can make charging/discharging decisions
  - Inverter can provide Utility with event and history logging
  - Inverter can provide Utility with capabilities and status reporting
  - System owner can allow or disable full Utility control over the system, and set limits for storage charge and discharge
  - Utility can communicate with individual systems, or broadcast to all PV inverters

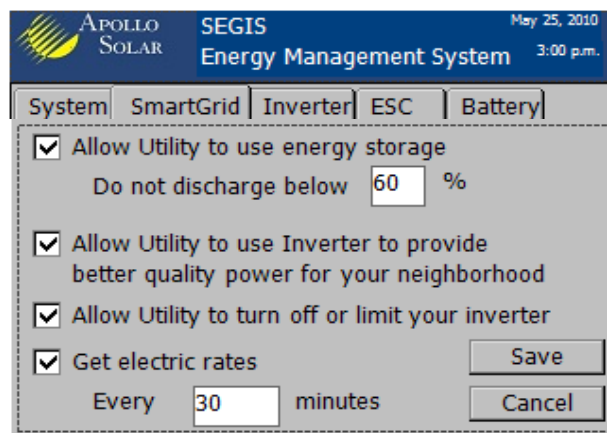
### **This communication portal on a grid tie inverter is the first of its kind.**

We provide the utility with complete control of the energy flow in the grid tie inverter and battery system.

Previously, the utility had absolutely zero control of any of the grid tie inverters installed on their grid.

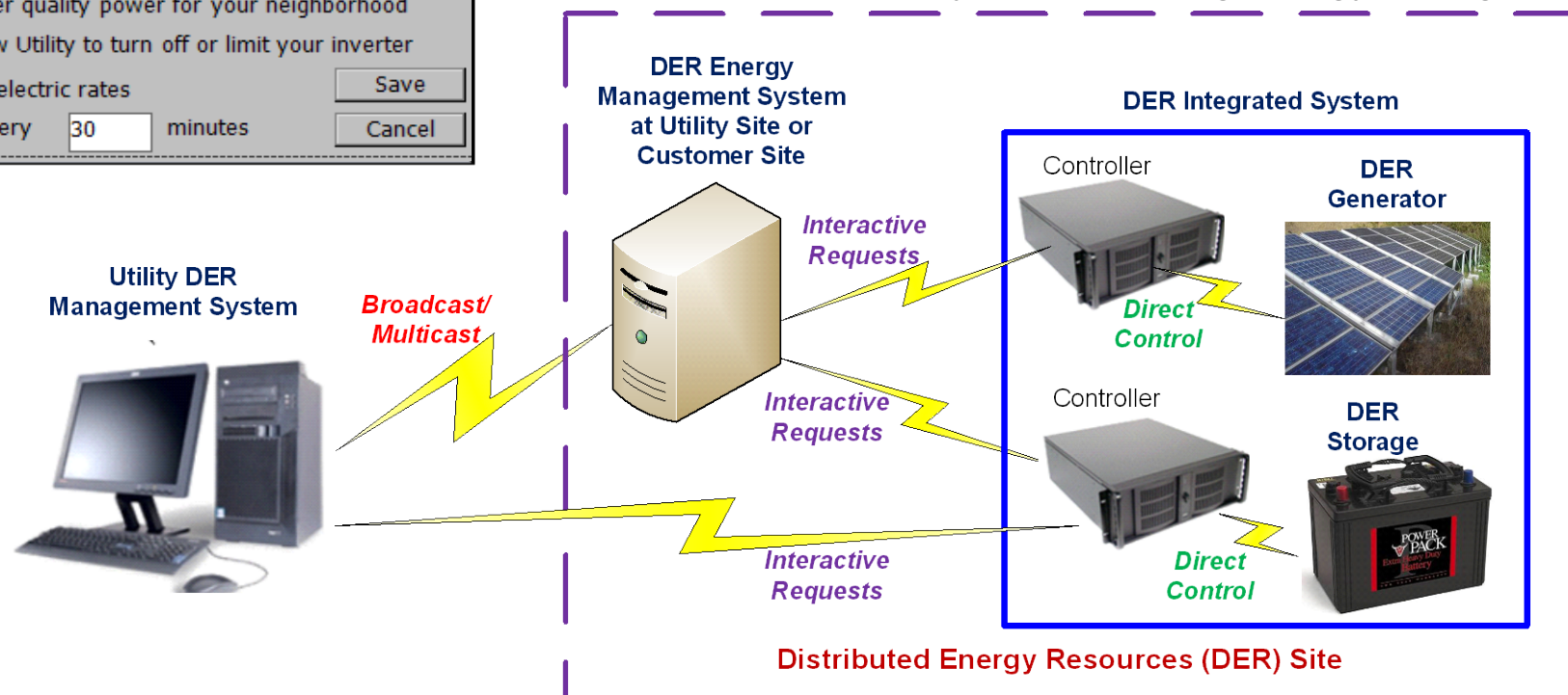
As a metric, we have taken the standard from essentially nothing to full control.

## Technical Accomplishment - Smart Grid Communications



Apollo System Controller – Energy Management System screen provides user with control of stored energy

Utility Communication System interfacing with the Apollo Smart Grid Inverter system including energy storage



**DER Management: Interactions between Components**

## **Technical accomplishment – Working prototype – The Objective of Stage 2**

- Developed the Energy Storage Converter topology as a dual active bridge based on the efficiency and flexibility for various battery voltages which may be used for future battery systems.
- Simulated the critical power circuits in the Energy Storage Converter.
- Completed the circuit design, printed circuit boards, and bill of materials for the Energy Storage Converter.
- Completed the thermal and mechanical design of the Energy Storage Converter to yield a 5kW DC to DC converter in a sealed enclosure with an external heat sink and no fans.
- Tested several grid tied inverters before selecting the best to meet expected performance.
- Finalized a business agreement granting Apollo Solar the exclusive rights to the grid tie inverter that provides framework and is modified to meet expected performance metrics.
- Developed and confirmed firmware for the Energy Storage Converter for bi-directional energy flow.
- Built and tested prototype boards and systems in all modes of operation.
- Completed witness testing at the Sandia Distributed Energy Technologies Lab (DETL) to prove functionality.

**Metric: Energy transfer from PV input to grid output was measured at 95%. The previous technology for grid tie with energy storage is in the area of 80% to 85%.**

**The Apollo Solar breakthrough is a unique inverter system because of the option to add energy storage at any time, unlike any other grid tie inverter sold in the US.**

**The Apollo Inverter System is also the first and only transformerless inverter to provide energy storage abilities. This energy storage is made accessible both to local loads and to the utility.**

- Cost sharing during Stage 2 was 80% from DOE and 20% from Apollo Solar.
- Cost sharing during Stage 3 will be 50% from DOE and 50% from Apollo Solar.
- The Apollo Solar SEGIS Stage 2 contract to design, build and test a prototype is on budget with time and dollars. The prototype may require additional time to fine tune the performance to achieve the optimum specifications. This can be accomplished prior to, or as part of the Stage 3 commercialization.
- Funding additional to the Stage 3 Commercialization contract is not anticipated in order to bring the product to market. However, the better product will result and commercialization can be expedited when more funding is available.
  - More units would be deployed during the field testing phase, yielding a more reliable product with features more closely defined to meet the market needs.
  - The addition of a PV Simulator to the budget would provide the means for enhancing the MPPT algorithm, thus producing a greater energy harvest from each inverter.
  - Additional testing of the prototypes would be done, including Highly Accelerated Life Tests which would enhance the reliability of the production units.

## **Commercialization of the prototype is the future plan for the following 12 months**

- Key milestones include Manufacturing, Engineering, UL certification, Pilot Production, and Field Testing.
- Remaining issues include production-costs reduction and a contingency path if the Energy Storage Converter proves too costly when meeting high-voltage battery technical requirements
- Length of time for UL certification of the Energy Storage Converter with first NRTL may also prove to be an issue. Mitigation plan is to make use of all reliably safe pathways to UL certification.

## **Beyond 2011, we have planned for the following future enhancements which flow directly from the prior work on the Smart Grid Inverter.**

**Each of the planned enhancements benefits from the modular nature of the Apollo SEGIS inverter System. Each module can be easily upgraded without affecting the other modules in the system, which is key to rapid and risk-controlled development.**

**The first milestone for each enhancement is the study of the market size and technical requirements which will yield the decision point to fund the specific development.**

- Connect the battery directly to the DC bus eliminating the cost of the DC to DC converter. This is an upgraded control algorithm in the Grid Tie Inverter.
- Enhancement of the Energy Storage Converter to include Lithium Ion batteries
- Upgrades in power to 6kW and then to 3 phase units of 30kW and beyond
- Control software upgrades to add functions such as VAR (Volt Amps Reactive) support
- Communication software additions to provide an interface with building EMS
- Communication software additions to provide an interface to AMI

Apollo Solar focused on the DOE mission of significantly reducing the cost of solar electricity by 2015, together with the addressing the technical concerns of the utility industry to the high-penetration of grid tie photovoltaics. We identified specific barriers in System Integration and are overcoming them as follows:

<u>Barrier or Challenge</u>	<u>Apollo Solar Solution</u>
Protection and coordination of energy flow must be addressed.	Added direct communication to and from the utility providing control of energy flows.
Intermittent nature of solar can create problems with grid stability.	Added Energy Storage which provides voltage and frequency regulation.
The supply of solar energy peaks earlier than the daily demand.	Energy Storage provides Peak Shaving or time shifting to match the demand curve.
Cost of inverters is becoming a larger percentage of the total system cost.	Eliminated the transformer which was often the single most expensive part.

Apollo Solar created a completely new topology for Grid Tie Inverter Systems and developed a completed prototype that includes a dual mode Grid Tie Inverter without a transformer, the Energy Storage Converter that provides Energy Storage that can be added at any time, and a System Controller with data communications with utilities.